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RECENT RESULTS ON LIGHT MESON PHYSICS

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ABSTRACT

Some recent results on light meson physics are reviewed. The new evidence of low mass scalar mesons together with the improved measurement of the ϕ radiative decays in scalar mesons, give new insight into the nature and the structure of the scalar spectrum. The evidence of new states with a mass close to twice the proton mass, and a new analysis of the gluonium content of η' are also discussed.

1 Introduction

The physics of light mesons has received in the last years several inputs from fixed target experiments with hadrons or photons beams and from e^+e^- experiments. The main aim of the published analyses is to clarify and to understand the very rich low mass (say below 2 GeV) mesons spectrum. In particular it is considered of primary importance to find signatures of physical states that cannot be interpreted as bound states of a quark and an antiquark ($q\overline{q}$). In fact QCD and QCD inspired models predict the existence of bound states of gluons (glueballs), of quark composites with more than 2 quarks (4-quark states $q\overline{q}q\overline{q}$) and of bound states of quarks and gluons (hybrid states $q\overline{q}$+gluon). All these states are generally called exotics.

In this paper some recent results in this field are presented and discussed.

2 Results on Scalar Mesons

The scalar meson spectrum is a place where the so-called exotics are particularly searched. In fact the number of experimentally found physical states with scalar quantum numbers (namely $J^{PC} = 0^{++}$) is larger than expected. So, while it is easy to accommodate pseudo-scalar ($J^{PC} = 0^{-+}$) and vector ($J^{PC} = 1^{--}$) mesons in $q\overline{q}$ SU(3) nonets, this is not true for scalar mesons. The list of the presently known scalar states is given in Tab.1. The states of the lowest mass $q\overline{q}$ nonet according to the Particle Data Group (PDG in the following [1]) are indicated in the table. As we shall see in the following the scalar nonet identification is still controversial and the PDG choice is only one among the possible interpretations.

New recent insight on light scalar mesons come from high statistics studies of three-body D-mesons and J/ψ decays, and from ϕ radiative decays.

2.1 New evidence of low mass scalar states: σ and κ

Three-body D-mesons and J/ψ decays are analysed looking at two-dimensional Dalitz plot distributions[2, 3, 4, 5]. This analysis has been applied to the following Dalitz plots:

- $D^+(D^+_{(s)}) \rightarrow \pi^+\pi^+\pi^-$ decays where any $\pi^+\pi^-$ pair is sensitive to scalar isoscalar intermediate states;
- $D^+ \rightarrow K^+\pi^+\pi^-$, $D^0 \rightarrow K^-\pi^+\pi^0$ and $D^0 \rightarrow K_S\pi^+\pi^-$ decays where any $K\pi$ pair is sensitive to isospin 1/2 scalar intermediate states;
- $J/\psi \rightarrow K^{*0}K^+\pi^-$ also sensitive to $K\pi$ isospin 1/2 states;

Table 1: *List of scalar states with mass below 1.8 GeV ordered in increasing mass. The states in parentheses are included in the $q\overline{q}$ lowest mass nonet by PDG.*

I=0	I=1/2	I=1
$f_0(400-1200)$ (σ)	$\kappa(700)$	$a_0(980)$
$f_0(980)$	$[K_0^*(1430)]$	$[a_0(1450)]$
$[f_0(1370)]$		
$f_0(1500)$		
$[f_0(1710)]$		

In order to fit the Dalitz plots two low mass broad states are introduced: a isoscalar σ and an isospin 1/2 κ. Each experiment suggests values for masses and widths of these states. These values are summarised in Fig.1. The values are in good agreement and the general indication is for an isoscalar state with a mass of 470 MeV and a width of 340 MeV and a isospin 1/2 state at 800 MeV with a width of 410 MeV. The broad σ state has been also introduced several times in the past, and its existence has always been considered controversial. Notice that the approach

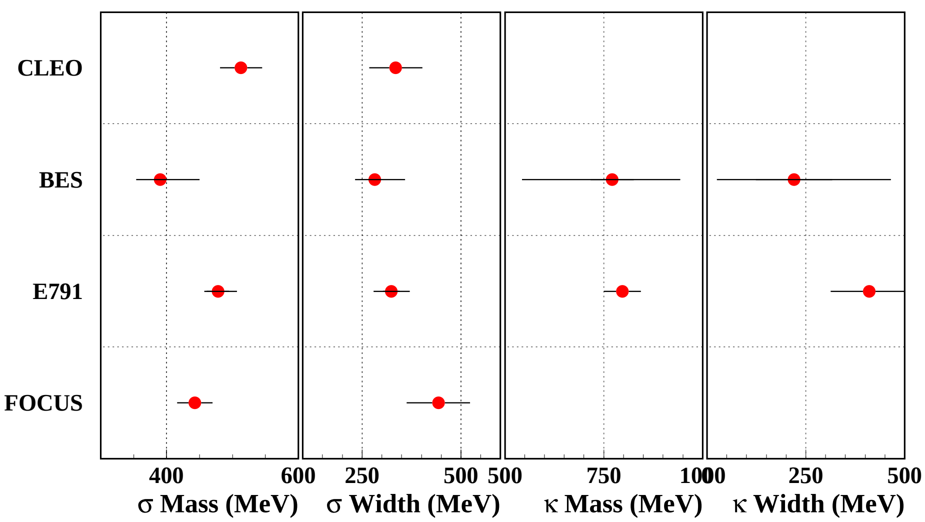

Figure 1: *Summary of recent results on masses and widths of σ and κ.*

used by these experiments to extract the informations on the scalar states, has been recently criticised [3, 6].

2.2 $f_0(980)$ and $a_0(980)$ in ϕ radiative decays

The $\phi(1020)$ is interpreted as an almost pure $s\bar{s}$ state. Due to the OZI rule the decays in final states not containing the s-quark are suppressed. In this context the branching ratio of a ϕ going to a meson plus a photon depends on the s-quark content of the meson itself.

At a ϕ factory (e^+e^- collider at 1020 MeV centre of mass energy) the scalar states $f_0(980)$, $a_0^0(980)$ and σ are accessible through the following final states:

- $\phi \to \pi^+\pi^-\gamma$ and $\phi \to \pi^0\pi^0\gamma$ where the two pions are in a scalar isoscalar state (IJ^{PC}=00^{++});
- $\phi \to \eta\pi^0\gamma$ where the $\eta\pi^0$ system is a scalar isovector state (IJ^{PC}=10^{++});

KLOE at the ϕ-factory DAFNE at Frascati has analysed the decays $\phi \to \pi^0\pi^0\gamma$ [7] and $\phi \to \eta\pi^0\gamma$ [8] [1] The observed branching ratios are both of the order 10^{-4}: $B.R.(\phi \to \pi^0\pi^0\gamma) = (1.08 \pm 0.05_{stat} \pm 0.03_{syst}) \times 10^{-4}$, $B.R.(\phi \to \eta\pi^0\gamma)_1 = (0.85 \pm 0.05_{stat} \pm 0.06_{syst}) \times 10^{-4}$ and $B.R.(\phi \to \eta\pi^0\gamma)_2 = (0.80 \pm 0.06_{stat} \pm 0.04_{syst}) \times 10^{-4}$, where the $B.R._{1,2}$ for the $\eta\pi^0\gamma$ decay, refer to 2 different η final states (namely $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$). The mass spectra of the $\pi^0\pi^0$ and $\eta\pi^0$ systems are shown in Fig.2. The spectra are fitted with a parametrisation based on the kaon-loop model [11] and turn out to be dominated by the scalar particle production, any other contribution being negligible[2] In the case of the $\pi^0\pi^0$ spectrum a good fit is obtained only including a σ with the same parameter and mass shape found by E791 [2], negatively interfering with the f_0 signal. If the quoted branching ratios are completely attributed to $\phi \to$ Scalar+γ decays, as it appears from the analysis of the spectra, the standard $q\bar{q}$ interpretation of f_0 and a_0 is in trouble. In fact the only possible quark compositions of f_0 and a_0 compatible with the observed mass degeneracy is: $f_0 \sim (u\bar{u} + d\bar{d})$ $a_0^0 \sim (u\bar{u} - d\bar{d})$ requiring branching ratios of the ϕ to $f_0\gamma$ or $a_0\gamma$ of the order of 10^{-6} (due to OZI suppression), that is 2 order of magnitude lower than the observed 10^{-4}.

On the other hand, this large branching ratio could be well explained in the context of $q\bar{q}q\bar{q}$ model where the f_0 and a_0 quark structure should be: $f_0 \sim$

[1] The first results on these decays have been obtained few years ago by SND and CMD-2 at VEPP-2M [9, 10], Novosibirsk. KLOE has improved by more than a factor 10 in statistics these results.

[2] Since the masses of f_0 and a_0^0 are very close to the mass of the ϕ the typical Breit-Wigner shape is distorted. It is essentially multiplied by a p_γ^3 factor, where p_γ is the momentum of the radiated photon.

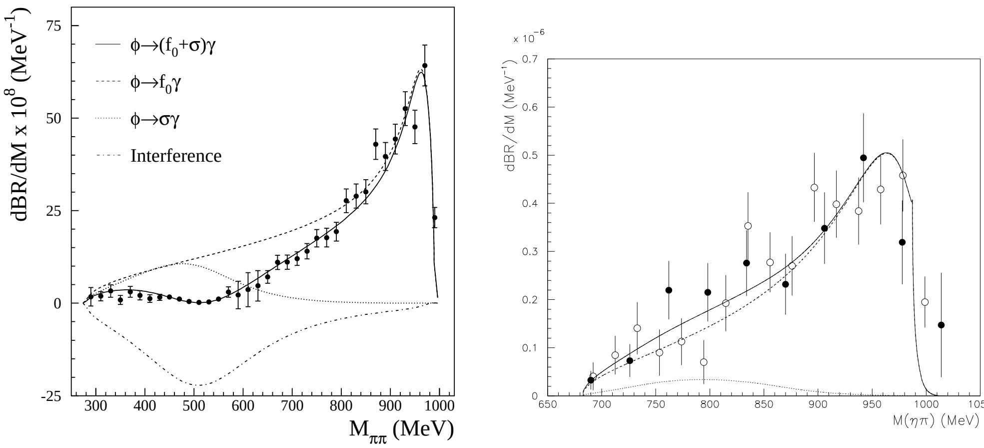

Figure 2: *Mass spectra of $\pi^0\pi^0$ (left) and $\eta\pi^0$ (right) final states from KLOE with fit superimposed.*

$(u\overline{u} + d\overline{d})s\overline{s}$ $a_0^0 \sim (u\overline{u} - d\overline{d})s\overline{s}$ both with an explicit $s\overline{s}$ pair. In this case the branching ratios should be of the order of 10^{-4}.

KLOE data on f_0 have been also analysed with an approach based on the K-matrix [12] aiming to get a model-independent conclusion. The result is dependent on the details of K-matrix used, but indicates that, in contrast to kaon-loop model result, only a part of the spectrum should be attributes to the f_0 production.

KLOE has now collected about 500 pb^{-1} while the results shown here corresponds to only 16 pb^{-1}. Higher accuracy results are expected soon, including also the decay $\phi \to \pi^+\pi^-\gamma$.

2.3 Possible scenarios

Looking at the scalar meson spectrum, 2 possible scenarios emerge, indicated in Fig.3. The first scenario assumes that σ and κ are real physical states. In this case there should be a lowest mass nonet where the states are "mass inverted" as expected for a 4 quark nonet [13], and a higher mass nonet with the PDG states. In this case only one state, the $f_0(1500)$ should remain out, and it could be of gluonium origin. The second scenario assumes that σ and κ are not real states and gives two standard nonets [14] (the second one could be the first radial excitation of the ground nonet). This scheme requires no s-quark content for $f_0(980)$ and $a_0(980)$ and so, it contradicts the current interpretation of ϕ radiative decays results.

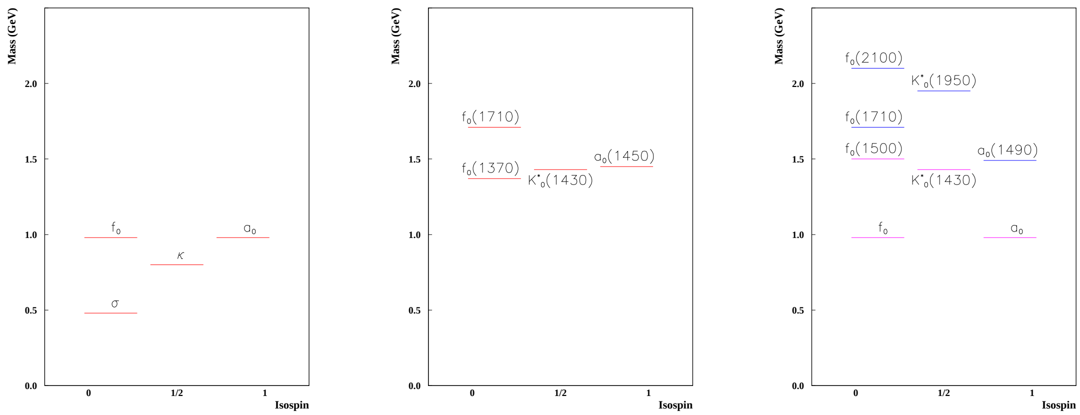

Figure 3: *The schemes 1 and 2 correspond to an inverted spectrum as suggested by the 4 quark model and to the PDG spectrum. The* $f_0(1500)$ *is excluded and could be the glueball. In scheme 3 the scalars are grouped in 2* $q\overline{q}$ *nonets (including a couple of higher mass states). In this scheme the* $f_0(1370)$ *is excluded.*

3 New states close to $2M_N$.

A second interesting subject is the recent claim of new states with an energy very close to twice the mass of the nucleon $2M_N$.

3.1 Evidence of a dip in 6 pion diffractive photo-production

The E687 experiment at Fermilab has analysed the data on diffractive photo-production of 6 pions, $3\pi^+3\pi^-$ [15]. This analysis was motivated by statistically limited indications from e^+e^- experiments [16, 17] of a structure in the region of $2M_N$. In order to select final state with vector quantum numbers, as in e^+e^- collisions, diffractive events are selected. This is done requiring the square of the total transverse momentum P_T^2 to be below 0.040 GeV^2. The invariant mass distribution of the 6 pion system for diffractive events shown in Fig.4 has a clear dip at about 1910 MeV (that is 30 MeV above $2M_N$) while the distribution for non-diffractive events doesn't show the dip. The fit shown is a coherent sum of a relativistic Breit-Wigner resonance with free mass and width and a diffractive continuum. A mass of 1911 ± 4 MeV and a width of 29 ± 11 MeV are obtained.

A state of similar mass has been also searched in $\overline{p}d \to p6\pi$ [18], and recently in $\overline{n}p$ annihilation in 6 pions by Obelix at LEAR [19]. No clear signal is found in this mass region. We notice that a signal in nucleon antinucleon annihilation could be interpreted as an indication for a baryonium state.

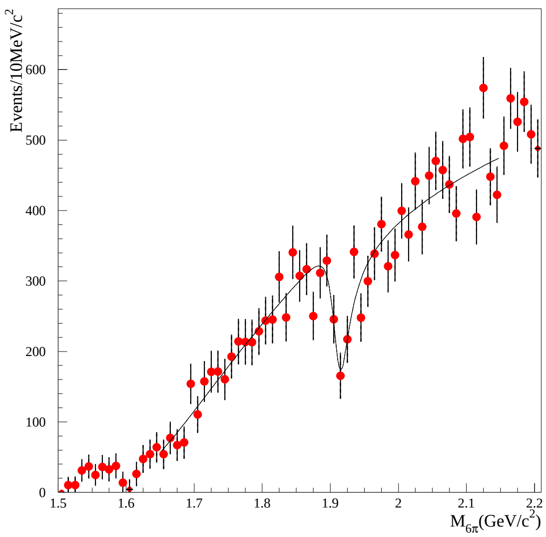

Figure 4: $3\pi^+3\pi^-$ *invariant mass distribution for diffractive events after correction for acceptance and unfolding of the resolution. The curve superimposed is the best fit. Data and fit from E687.*

3.2 Threshold enhancement in $J/\psi \to p\overline{p}\gamma$

Very recently the BES collaboration at the e^+e^- collider BEPC, Bejing, has reported a study of the decay $J/\psi \to p\overline{p}\gamma$ [20]. The invariant mass spectrum of the $p\overline{p}$ system is shown in Fig.5. It shows a clear enhancement very close to threshold.

$p\overline{p}\gamma$ final states could be due either to J/ψ radiative decay (in this case the $p\overline{p}$ system is expected to have scalar or pseudo-scalar quantum numbers) or to radiative return on $e^+e^- \to p\overline{p}$ due to the time-like proton form factors (vector quantum numbers). BES angular analysis of the events close to threshold suggests radiative decays rather than radiative return.

BES has tried a fit in both scalar and pseudo-scalar state hypotheses. The values obtained for the masses are: 1859^{+3}_{-10} MeV (pseudo-scalar hypothesis) and 1867.4 ± 0.9 MeV (scalar hypothesis). In both cases the state is very narrow: $\Gamma = 0 \pm 21$ MeV (pseudo-scalar hypothesis) and 4.6 ± 1.8 MeV (scalar hypothesis).

3.3 Summary

The states observed by E687 and by BES are apparently of different quantum numbers and of significantly different mass. So they have a different origin. Several experiments can search for these states: FOCUS can statistically improve the E687

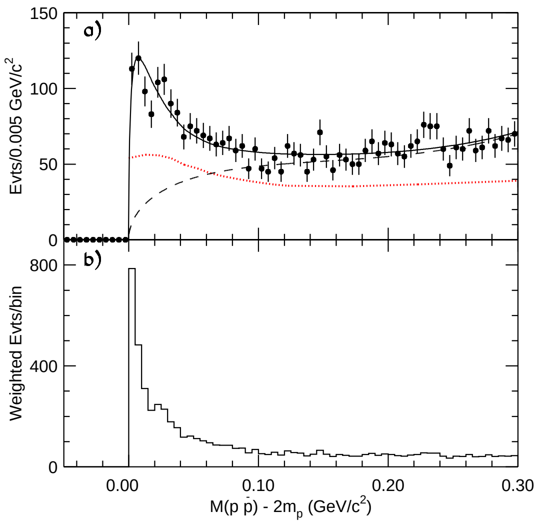

Figure 5: *(a) $M(p\overline{p}) - 2M_p$ distribution near threshold for $p\overline{p}\gamma$ events with fit superimposed. (b) Same distribution corrected for phase-space. Data from BES.*

signal; BABAR and BELLE can access to 6 pions and $p\overline{p}$ production through initial state radiation, and study exclusive B decays with $p\overline{p}$ in the final state [21]; finally CLEO-C will study J/ψ decays. We notice that a mass value of 1.9 GeV, other than close to the nucleon-antinucleon threshold, is also the typical predicted value of the mass of the hybrid states in the context of the tube-flux model [22].

4 Gluonium content of η'

The pseudo-scalar meson $\eta'(958)$ is considered a possible glueball candidate, or at least a $q\overline{q}$ state strongly mixed with a glueball. The η' wave function can be written as:

$$|\eta' >= X_{\eta'}|(u\overline{u} + d\overline{d})/\sqrt{2} > +Y_{\eta'}|s\overline{s} > +Z_{\eta'}|\text{glueball} >$$

Since the ϕ is an almost pure $s\overline{s}$ state, the decay $\phi \to \eta'\gamma$ selects the $Y_{\eta'}$ component of the η' wave function.

KLOE has measured this decay with improved precision respect to previous measurements [23]. If $Z_{\eta'} = 0$, one has $X_{\eta'}^2 + Y_{\eta'}^2 = 1$. The last condition can be checked using together the $Y_{\eta'}$ value extracted by KLOE and two other results on η' decays[3] and putting them in the graph shown in Fig.6. The crossing of the three bands is compatible with the condition $X_{\eta'}^2 + Y_{\eta'}^2 = 1$. This means that at this level of experimental accuracies, there is no indication of a gluonium content of the η'.

[3]The two vertical bands are obtained using the PDG values for $\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma)$ and for $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$.

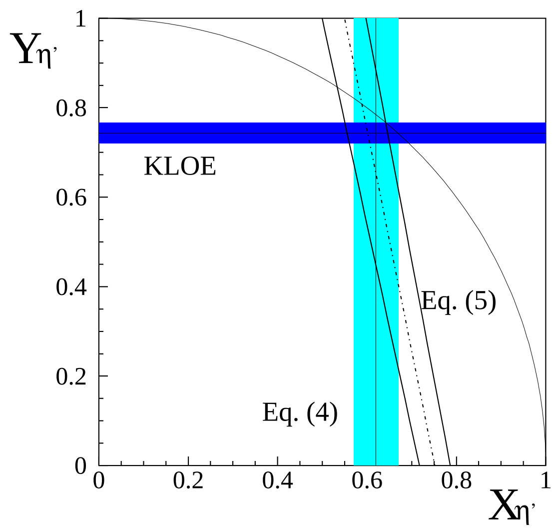

Figure 6: *Bounds in the $X_{\eta'}$-$Y_{\eta'}$ plane from experimental branching fractions and SU(3) based calculations.*

From the directly measured ratio of $\phi \to \eta\gamma$ and $\phi \to \eta'\gamma$, assuming $Z_{\eta'} = 0$ and $Z_\eta = 0$ KLOE has determined the pseudo-scalar mixing angle in the flavour basis ϕ_p to be:

$$\phi_p = (41.8^{+1.9}_{-1.6})^\circ$$

5 Conclusions

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References

1. K. Hagiwara *et al.*, Phys.Rev. **D66** 010001 (2002).

2. E.M. Aitala *et al.*, Phys.Rev.Lett.**86** 770 (2001); E.M. Aitala *et al*, Phys.Rev.Lett.**89** 121801 (2002).

3. S. Malvezzi, talk given at Photon2003 (see *http://www.lnf.infn.it*)

4. N. Wu, talk given at 36th Rencontres de Moriond 2001, hep-ex/0104050; J.Z. Bai *et al.*, submitted to Phys.Rev.Lett., hep-ex/0304001.

5. H. Muramatsu *et al.*, Phys.Rev.Lett.**89** 251802 (2002) Erratum-ibid **90** 059901 (2003).

6. V.V. Anisovich, L.G. Dakhno, V.A.Nikonov, hep-ph/0302137.

7. A. Aloisio *et al.*, Phys.Lett. **B537** 21 (2002).

8. A. Aloisio *et al.*, Phys.Lett. **B536** 209 (2002).

9. M.N. Achasov *et al.*, Phys.Lett. **B485** 349 (2000); M.N. Achasov *et al.*, Phys.Lett. **B479** 53 (2000).

10. R.R. Akhmetshin *et al.*, Phys.Lett. **B462** 380 (1999);

11. N.N. Achasov, V.N. Ivanchenko, Nucl.Phys. **B315** 465 (1989).

12. M. Boglione, M.R. Pennington, hep-ph/0303200.

13. R.L. Jaffe, Phys.Rev. **D15** 281 (1977).

14. E. Klempt, talk given at PSI Zuoz Summer School, 2000, hep-ex/0101031.

15. P.L. Frabetti *et al.*, Phys.Lett. **B514** 240 (2001).

16. R. Baldini *et al.*, talk given at the Fenice Workshop, Frascati 1988.

17. A. Antonelli *et al.*, Phys.Lett. **B365** 427 (1996).

18. M. Gaspero, talk given at Workshop on Hadron Spectroscopy Frascati March 1999, Frascati Physics Series Vol.XV 455 (1999).

19. M.Agnello *et al.*, Phys.Lett. **B529** 39 (2002).

20. J.Z. Bai *et al.*, submitted to Phys.Rev.Lett. hep-ex/0303006.

21. K Abe *et al.*, Phys.Rev.Lett. **89** 15182 (2002); K. Abe *et al.*, Phys.Rev.Lett. **88** 18183 (2002).

22. N. Isgur, A. Kokosky, J. Paton, Phys.Rev.Lett. **54** 869 (1985).

23. A.Aloisio *et al.* Phys.Lett. **B538** 21 (2002).